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ASSESSMENT OF GREENHOUSE GAS (GHG) EMISSIONS ASSOCIATED WITH RAPESEED FARMING IN ROMANIA

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ABSTRACT. Agriculture plays a role in greenhouse gas (GHG) emissions, especially by cultivating biofuel crops like rapeseed (*Brassica napus*). This study assesses the GHG emissions associated with rapeseed farming in Romania, focusing on 2022–2024. Data were collected from rapeseed cultivation at Mihai Viteazu, Cluj, under various fertilization and irrigation conditions. The study reveals that GHG emissions range from 89 to 231 kg CO_2 eq/l biodiesel, with irrigation reducing emissions by approximately 1.3 times compared to non-irrigated conditions. Notably, nitrogen fertilization significantly increases nitrous oxide (NOx) emissions, which account for 80% of total GHG emissions, particularly under higher nitrogen application rates. The results highlight the need for optimized nitrogen management to balance yield increases with environmental impacts, as excessive nitrogen use intensifies NOx emissions due to enhanced nitrification and denitrification processes. The study also finds that irrigation mitigates GHG and NOx emissions, emphasizing its role in sustainable rapeseed farming. This research underscores the importance of precision nitrogen management and irrigation in reducing the carbon footprint of rapeseed biodiesel production while enhancing crop productivity in Romania.

Keywords: *greenhouse gas emissions, GHG, rapeseed farming, nitrogen fertilization, biofuels, sustainable agriculture*

INTRODUCTION

Rapeseed (*Brassica napus*) is one of the most widely grown oilseed crops in the world, playing a crucial role in both the agricultural and biofuel sectors. Its cultivation and use in biofuel production significantly affect greenhouse

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gas (GHG) emissions and global climate change mitigation efforts. Agricultural practices, particularly nitrogen fertilization and irrigation, have been identified as key factors influencing GHG emissions from rapeseed farming, especially in the context of nitrous oxide (N_2O) emissions, potent contributors to global warming [1, 2].

The environmental impacts of rapeseed cultivation have been widely researched, revealing that nitrogen management practices and irrigation methods significantly affect GHG emission levels in rapeseed fields [3, 4]. In regions such as Eastern Europe, and specifically Romania, the importance of sustainable rapeseed cultivation is paramount, given its role in biofuel production and the region's agricultural economy [5]. Studies have demonstrated that adopting more sustainable farming practices can lead to significant reductions in GHG emissions from rapeseed cultivation, particularly through improved nitrogen use efficiency and better irrigation management [6, 7].

Recent assessments of biofuel production systems have emphasized the need for a life cycle approach to evaluate the full environmental impact of rapeseed biodiesel, from cultivation to fuel combustion. Such evaluations are critical for understanding the potential GHG savings associated with rapeseed biofuels and their role in meeting international climate targets, including those set by the European Union's Directive 2009/28/EC, which promotes the use of renewable energy sources [8, 9, 17, 23]. In this context, life cycle assessments (LCAs) have been used to quantify GHG emissions across the biofuel production chain, highlighting the importance of both agricultural practices and energy inputs in determining the overall carbon footprint of rapeseed biodiesel [10, 11, 19]. To contextualize the findings, comparisons with studies from other European countries indicate that the GHG emissions from Romanian rapeseed biodiesel are comparable to those reported for Germany (63-68 g CO_2 eq/MJ) and Sweden (66-70 g CO_2 eq/MJ), with Romanian figures ranging between 62-75 g CO_2 eq/MJ. These values suggest that Romania aligns closely with sustainable benchmarks while highlighting areas for potential improvement [24, 25].

Furthermore, irrigation practices and their impact on GHG emissions have gained attention in recent studies. The use of irrigation in rapeseed farming can lead to higher biomass production, but it also increases the risk of N_2O emissions due to enhanced nitrogen availability in the soil [12]. Comparative studies between irrigated and non-irrigated systems suggest that while irrigation may boost yields, it can also exacerbate GHG emissions if not managed carefully [13,14,15]. Similar findings were reported in France, where irrigated rapeseed cultivation increased yields by 20-30% but contributed to a 15-18% rise in N_2O emissions, illustrating the delicate trade-offs involved [26].

As such, optimizing both irrigation and fertilization practices is essential for reducing the environmental footprint of rapeseed cultivation [15].

Given these challenges, this study aims to provide a comprehensive assessment of the GHG emissions associated with rapeseed cultivation in Romania. The research focuses on critical aspects such as nitrogen fertilization strategies, soil management practices, and carbon sequestration potential. It is widely understood that nitrogen fertilization plays a crucial role in rapeseed production, but improper management can lead to significant emissions of nitrous oxide (N_2O), a potent GHG. Similarly, soil management practices, particularly tillage methods, can influence soil organic carbon levels, which are important for carbon sequestration [16, 18, 20, 21].

By optimizing these variables—such as selecting nitrogen fertilizers with lower emission profiles, fine-tuning nitrogen application rates, and adopting reduced or no-tillage farming methods—it may be possible to significantly reduce the GHG emissions associated with rapeseed biodiesel production. This study not only evaluates the direct effects of these practices on emission levels but also explores their potential to enhance soil carbon sequestration, thereby contributing to long-term climate mitigation strategies. The findings offer valuable insights into the pathways for producing more sustainable biofuels in Romania, and they align with broader efforts to lower the agricultural sector's GHG emissions, while supporting the transition to cleaner energy sources [22].

RESULTS AND DISCUSSION

For GHG calculations, data from rapeseed cultivation under Mihai Viteazu, Cluj conditions (2022–2024) were used. Specific treatments included:

- **Disease, Pest, and Weed Management:**
  - **Seed treatment:** ROVRAL 50 WP was applied at 1 kg/tonne.
  - **Vegetation treatment**: FOLICUR SOLO (Bayer CropScience) was applied at 0.5 l/ha. Diseases such as rust, powdery mildew, downy mildew, and alternariosis were managed using the same treatments: ROVRAL 50 WP at 1 kg/tonne for seeds and FOLICUR SOLO at 0.5 l/ha for vegetation.
  - **Pest control**: Ground fleas, rape beetle, cruciferous weevils, and green aphids were treated with MELIPAX 60 EC at 3 l/ha during flowering. Glossy beetles and rape wasps were controlled with VICTENON at 0.75 kg/ha.

- **Weed control**: DUAL was applied as a pre-sowing treatment at 3–4 l/ha, while post-sowing treatment utilized LONTREL at 0.3–0.5 l/ha.

- **Fertilization Regimes:**

  Fertilization was carried out in three gradations:
  - **B_2**: 100 kg/ha nitrogen, 75 kg/ha phosphorus, and 20 kg/ha sulfur.
  - **B_3**: 150 kg/ha nitrogen, 75 kg/ha phosphorus, and 20 kg/ha sulfur.
  - **B_4**: 270 kg/ha nitrogen, 75 kg/ha phosphorus, and 20 kg/ha sulfur.

Additionally**, NUTRIENT EXPRESS® (Miller)** was applied at 2.5 kg/ha.This fertilizer contains a high concentration of microelements, seaweed extract, carbohydrates, and essential amino acids, with the following composition:

- 18% total nitrogen (4.9% ammonia, 5.5% nitrate, and 7.6% urea nitrogen)
- 18% mobile phosphorus (P_2O_5)
- 18% soluble potassium (K_2O)
- Chelated microelements: 0.05% copper (Cu), 0.10% iron (Fe), 0.50% magnesium (Mg), 0.05% manganese (Mn), 0.001% molybdenum (Mo), and 0.05% zinc (Zn).

- **Foliar Fertilization:**

FOLICARE 17-9-33 (Yara Suomi) was applied at 5 kg/ha. This high-efficiency fertilizer contains 2000 mg/kg boron (B) and has the following composition:

- 8% nitrogen (N)
- 9% phosphorus (P_2O_5)
- 33% potassium (K_2O)
- 2% magnesium oxide (MgO)
- 5% sulfur trioxide (SO_3)
- Trace elements: 0.02% copper (Cu), 0.05% iron (Fe), 0.05% manganese (Mn), 0.002% molybdenum (Mo), and 0.05% zinc (Zn).

Table 1 shows the GHG emissions recorded for all the cultivation variants tested at Mihai Viteazu - Cluj during 2022-2024. Since the rapeseed is cultivated for biofuel production, the GHG emissions per liter of biodiesel produced were calculated. GHG emissions are expressed in carbon dioxide equivalent CO2 eq/l biodiesel (CO2 eq) is the universal unit of measure used to indicate the global warming potential of GHG). Carbon dioxide is the reference gas by which all greenhouse gases are calculated and reported.

Table 1. GHG emissions, calculated for the rapeseeds crop variants realized at Mihai Viteazu - Cluj, 2022- 2024

Crop variants	Average yield (t/ha)	GHG emissions (kg CO2 eq/l)	NO_x emissions from soils (kg CO2 eq/l)
[a]a1 x [c]b1 nonirrigated x nonfertilized	16,882	0,013	0,001
[a]a1 x [d]b2 nonirrigated x fertilized 100N	19,415	0,089	0,076
[a]a1 x [e]b3 nonirrigated x fertilized 150N	23,127	0,107	0,096
[a]a1 x [f]b4 nonirrigated x fertilized 270N	24,480	0,175	0,162
[b]a2 x [c]b1 irrigated x nonfertilized	21,104	0,010	0,001
[b]a2 x [d]b2 irrigated x fertilized 100N	27,856	0,062	0,053
[b]a2 x [e]b3 irrigated x fertilized 150N	31,232	0,079	0,071
[b]a2 x [f]b4 irrigated x fertilized 270N	32,581	0,131	0,122

[a]a_1- non-irrigated; [b]a_2-irrigated; [c]b_1-fertilized; [d]b_2- fertilized 100kg/ha azote(N)+75 kg/ha phosphorus(P)+20 kg/ha sulphur (S) ; [e]b_3-fertilized 150kg/ha azote(N)+75 kg/ha phosphorus(P)+20 kg/ha sulphur (S); [f]b_4-fertilized 270kg/ha azote(N)+75 kg/ha phosphorus(P)+20 kg/ha sulphur (S);

Figures 1-3 show the average productions of the rapeseed crop recorded in 2008, the GHG emissions associated with them due to the fertilizers and pesticides used, as well as the NOx emissions due to the nitrogen fertilization of the rapeseed crop.

The influence of the experimental factor B, fertilization, on rapeseed culture: average production, GHG emissions and NOx emissions from associated soils

The analysis of the results presented in **Table 1** highlights the following situations for the rape culture variants tested.

Control sample: non-irrigated x non-fertilized. NOx emissions from soil represent 7.6% of total GHG emissions.

The experimental factor B, fertilization, graduation b2 (nitrogen dose of 100 kg/ha) had a significant influence and determined an increase in production of 2533 kg/ha (15%), an increase in GHG emissions by 6.8 times and a 76-fold increase in NOx emissions compared to the experimental control. In the experimented culture variant (graduation a1 x b2) NOx emissions represent 85% of total GHG emissions.

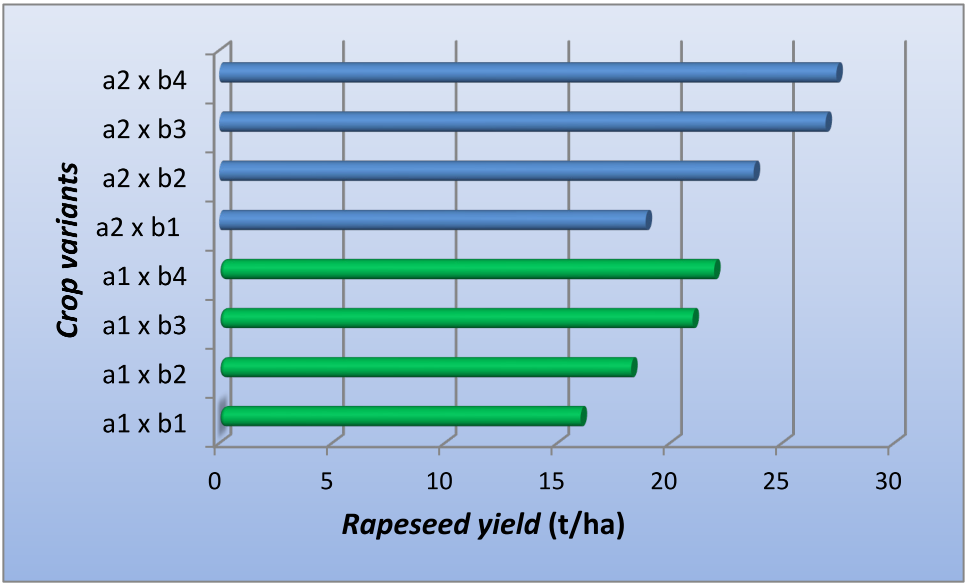

Figure 1. Yield of rapeseed crop obtained for the experimented crop variants, 2022-2024

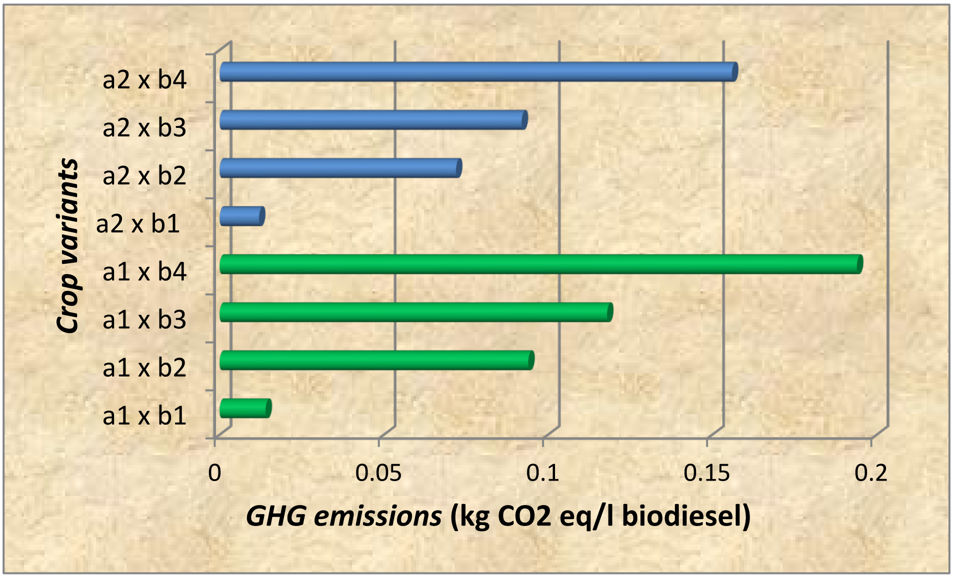

Figure 2. GHG emissions calculated for the rapeseed crop variants, Mihai Viteazu - Cluj, 2022-2024

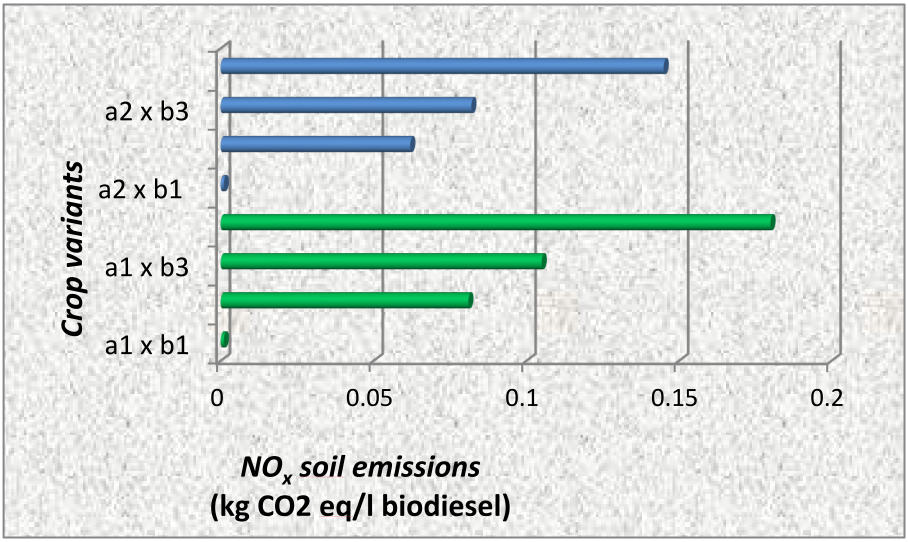

Figure 3. NOx emissions from soils calculated for the rapeseed crop variants, Mihai Viteazu - Cluj, 2022-2024

By fertilizing during the growing season of the crop, type b3 (nitrogen dose of 150 kg/ha), an increase in production of 6245 kg/ha (36.9%), an increase in GHG emissions by 8.2 times was obtained and NOx emissions 96 times, compared to the control variant chosen. In this crop variant (graduation a1 x b3) the NOx emissions from the soil represent 89% of the total GHG emissions.

It is found that if, during the growing season of the crop, fertilization is applied with grading b4 - the nitrogen dose of 270 kg/ha, a production increase of 5296 kg/ha (45.0%), an increase in GHG emissions of 13.4 times and 162 times of NOx emissions, compared to the chosen witness. NOx emissions from the soil represent 92% of total GHG emissions in the experimented crop variant (a1 x b4 grading).

Control sample: irrigated x unfertilized. NOx emissions from soil represent 10% of total GHG emissions.

When applying fertilization, grading b2 - the nitrogen dose of 100 kg/ha has a great influence on rapeseed culture and led to an increase in production of 4896 kg/ha (30.5%), an increase in GHG emissions of 5 .8 times and of NOx emissions from the soil 71 times, compared to the control version of the experiment NOx emissions from the soil have a weight of 85.4% of total GHG emissions in the experimented version (a2 x b2 grading).

Experimental factor B, fertilization, graduation b3 - nitrogen dose of 150 kg/ha, influenced rape production and determined an increase of 10128 kg/ha (47.9%), an increase of GHG emissions by 7.9 times and of NOx emissions from the soil 71 times compared to the control variant chosen. In this case, (grading a2 x b3) NOx emissions from the soil represent a percentage of 89% of total GHG emissions.

It was observed that even with the application of fertilization grade b4 (nitrogen dose of 270 kg/ha), there was a 54.3% increase in yield to 11,477 kg/ha, along with a 13.1-fold rise in GHG emissions and a 122-fold increase in NOx emissions from the soil compared to the control. NOx emissions accounted for 91.7% of the total GHG emissions (a2 x b4 level). Analyzing the results, it is evident that fertilization (factor B) greatly influenced the crop, leading to higher GHG and NOx emissions from the soil across all tested variants. As nitrogen doses increased, both GHG and NOx emissions from the soil also rose.

Comparisons with other European data reveal a similar trend, where increasing nitrogen application consistently increases GHG emissions. For instance, research in Denmark observed a 12- to 15-fold rise in N_2O emissions when nitrogen application increased from 90 kg/ha to 270 kg/ha [26]. This aligns closely with the findings from this study, where NOx emissions increased by 13.4 times under similar nitrogen fertilization rates.

The influence of the experimental factor A, irrigation regime, on rapeseed culture: average production, GHG emissions and NOx emissions from associated soils

Compared to the non-irrigated x non-fertilized control variant, the application, during the vegetation period of the crop, of irrigation (graduation a2 x b1) leads to production in the rapeseed crop with an increase of 4222 kg/ha (25%), a decrease in GHG emissions of 1.3 times, and equal emissions of NOx from the soil for both variants.

The application of irrigation during the vegetation period of the crop (graduation a2 x b2) determined an increase in production of 8441 kg/ha (43.4%), a decrease in GHG emissions by 1.4 times and NOx emissions from the soil by 1,3 times, compared to the non-irrigated x fertilized control version - grading b2.

Compared to the non-irrigated x fertilized control variant - grading b3, the application of irrigation (grading a2 x b3) determined an increase in production of 8105 kg/ha (35.0%), a decrease in GHG emissions by 1.35 times and emissions NOx from soil 1.35 times.

It is found that by applying irrigation during the growing season of the crop, there was an increase in production of 8101 kg/ha (33.0%), a decrease in GHG emissions by 1.3 times and NOx emissions from the soil by 1.3 times compared to the non-irrigated x fertilized control variant - grading b4.

Upon analyzing the results, it is evident that experimental factor A, the irrigation regime, specifically at the a2-irrigated level, significantly impacts the crop by reducing both GHG and NOx emissions from the soil across all tested variants.

At a first analysis of the obtained results, the best crop variant seems to be irrigated x fertilized - grading b4 in which the production recorded an increase of 54.3%, compared to 47.9% - the variant irrigated x fertilized - grading b3 but, analyzing from the point of view of the impact on the environment, we recommend the irrigated x fertilized crop variant - grading b3 because the increase in GHG emissions is only 7.9 times compared to 13.1, and the NOx emissions from the soil are only 71 times times compared to 122.

Method of Calculating GHG and NOx Emissions (Carbon Dioxide Equivalent)

The method for calculating GHG emissions, particularly NOx emissions in carbon dioxide equivalent, follows standard guidelines from the Intergovernmental Panel on Climate Change (IPCC) and the European Commission's Joint Research Centre (JRC) for life cycle assessments (LCAs). The CO_2 equivalent is calculated by multiplying the amount of each gas emitted by its respective Global Warming Potential (GWP) factor [27].

For example, nitrous oxide (N_2O) has a GWP of 298, meaning that one kilogram of N_2O is equivalent to 298 kilograms of CO_2. The emissions from fertilizers are calculated based on the amount of nitrogen applied and the emission factors provided by the IPCC guidelines for agricultural practices. The NOx emissions are primarily calculated from soil nitrogen dynamics (nitrification and denitrification processes), which are influenced by fertilizer types and application methods.

CONCLUSIONS

The study conducted at Mihai Viteazu between 2022 and 2024 provides valuable insights into the greenhouse gas (GHG) emissions associated with rapeseed cultivation under various conditions. The findings indicate that GHG emissions vary significantly depending on whether the crops are irrigated or not. Specifically, in 2022, GHG emissions ranged from 89 to 175 kg CO2 eq/l under non-irrigation conditions and from 62 to 131 kg

CO2 eq/l under irrigation conditions. In 2023, these values increased to 117 to 231 kg CO2 eq/l for non-irrigated crops and 82 to 180 kg CO2 eq/l for irrigated crops. Similarly, in 2024, GHG emissions were recorded at 94 to 194 kg CO2 eq/l under non-irrigation and 72 to 156 kg CO2 eq/l under irrigation.

The study also highlights the significant contribution of NOx emissions from soils, particularly in fertilized crop variants. In 2022, NOx emissions ranged from 76 to 162 kg CO2 eq/l under non-irrigation and 53 to 122 kg CO2 eq/l under irrigation. The following year, these emissions increased to 101 to 214 kg CO2 eq/l for non-irrigated crops and 71 to 167 kg CO2 eq/l for irrigated crops. In 2024, NOx emissions were recorded at 81 to 180 kg CO2 eq/l under non-irrigation and 62 to 145 kg CO2 eq/l under irrigation.

The results show that NOx emissions from soils contributed to an average of 80% of the total GHG emissions across all variants. This underscores the significant role of nitrogen fertilizers in increasing soil NOx emissions, largely due to intensified nitrification and denitrification processes. The increase in NOx output highlights the challenge of balancing the need for nitrogen fertilization to boost yields with its environmental impact. Excessive nitrogen application can exacerbate these processes, resulting in higher GHG emissions.

The study emphasizes that nitrogen fertilization is necessary to achieve higher crop yields, but this comes at the cost of increased GHG emissions. Fertilizer application, while essential for boosting agricultural productivity, must be optimized to prevent excessive nitrogen use. To mitigate emissions, it is crucial to match nitrogen input precisely to the crop's requirements and adopt more efficient nitrogen management techniques. This may involve enhancing nitrogen use efficiency (NUE) to ensure crops absorb nutrients more efficiently, thereby reducing nitrogen losses to the environment.

The data also show a consistent decrease in both GHG and NOx emissions with the application of irrigation. This suggests that irrigation not only promotes improved crop growth but also reduces emission intensity per unit of production. By maintaining optimal soil moisture levels, irrigation helps minimize nitrogen losses through volatilization and leaching, ultimately reducing total emissions.

The findings from 2022 to 2024 for rapeseed cultivation at Mihai Viteazu, Cluj, reinforce the importance of balanced nitrogen fertilization for improving yields while minimizing environmental impact. The application of irrigation proves beneficial in reducing GHG and NOx emissions, suggesting that integrating these practices can help achieve more sustainable rapeseed farming. When benchmarked against other European studies, Romanian rapeseed cultivation demonstrates a comparable environmental profile, with opportunities for further optimization. For example, adopting advanced precision farming techniques, as successfully implemented in Sweden, could reduce nitrogen-related emissions by up to 25% while maintaining yield efficiency [25]. Future strategies should focus on precision nitrogen management and controlled irrigation to optimize production efficiency and reduce the carbon footprint associated with rapeseed biodiesel production.

In conclusion, although nitrogen fertilization is crucial for optimizing rapeseed yields, its effect on GHG and NOx emissions requires careful management. Implementing more efficient nitrogen use practices and irrigation can greatly lessen the environmental impact of rapeseed cultivation, making it a more sustainable choice for biofuel production in Romania.

EXPERIMENTAL SECTION

Rapeseed culture was carried out on an experimental lot in Mihai Viteazu, Cluj County. The studied perimeter is located in the Transylvanian Plain, its southwestern limit, in the lower region of the Aries hydrographic basin. The town of Mihai Viteazu is located on DN 75, approx. 45 km from the city of Cluj-Napoca (**Figure 4** source: http://www.hartionline.ro). The geographical position corresponds to the coordinates 46° 34' north latitude and 23° 46' east longitude Greenwich and an altitude of 345 - 493 m compared to the level of the Adriatic Sea.

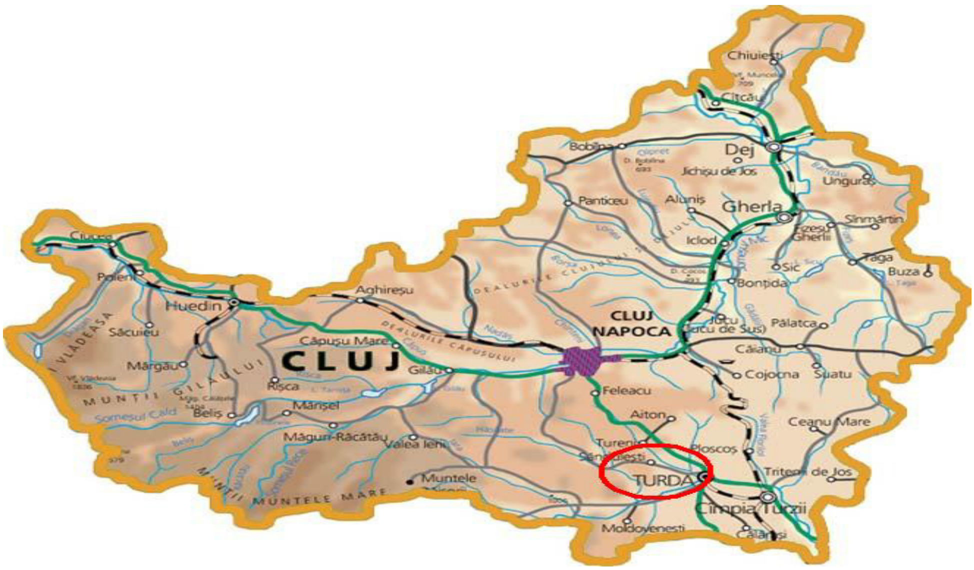

Figure 4. The location of the experimental field in Cluj County (source: www.hartionline.ro)

The comparative crops were developed in a polifactorial system, completely randomized, with subdivided parcels, as factor A is the water regime (two graduations), factor B is fertilization (four graduations) and factor C – rapeseed variety (three graduations), the biological material chosen. Three repetitions were provided for each comparative crop. Irrigation was performed by furrows. The experiments contained several 3 repetitions (n = 3), the number of varieties analyzed through the experiment was 24 (v = 2 x 4 x 3), the total number of experimental parcels was 72 (p = 24 x 3) (**Figure 5**). The experimental factors studied and their graduations are briefly presented in **Table 2**.

Table 2. Summary of the experimental factors, Mihai Viteazu - Cluj, 2022-2024

Analyzed factors	Graduations
Factor A **Irrigation regime**	a_1 –non-irrigated
	a_2 – irrigated at 50% from IUA
Factor B **Fertilization**	b_1 –non-fertilized
	b_2 – fertilized 100 N kg/ha + 75 kg /ha phosphorus + 20 kg/ha sulphur
	b_3 – fertilized 150 N kg/ha + 75 kg /ha phosphorus + 20 kg/ha sulphur
	b_4 – fertilized 270 N kg/ha + 75 kg /ha phosphorus + 20 kg/ha sulphur
Factor C **Rapeseed variety**	c_1 – Dexter
	c_2 - NK Caravel
	c_3 – NK Tehnic

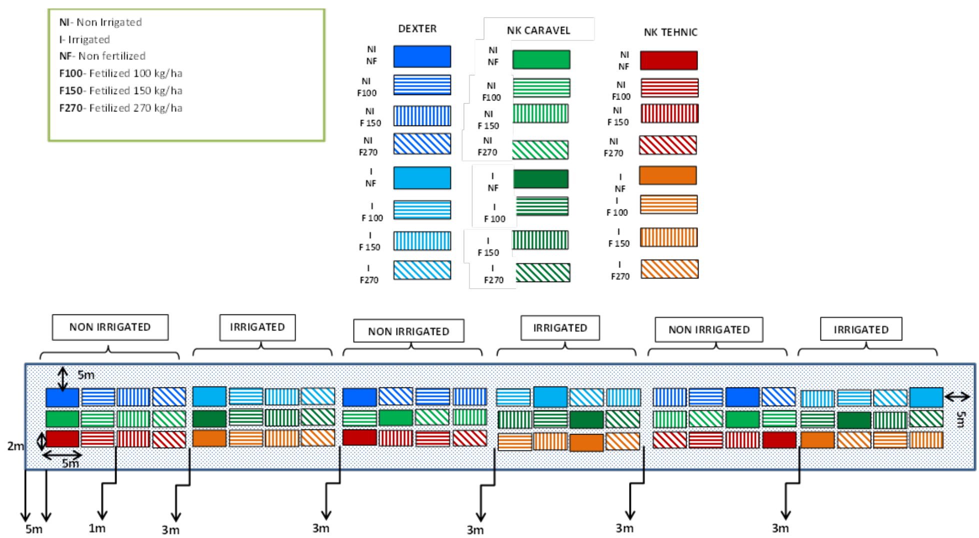

Figure 5. The research organization in the experimental filed

For the statistical analysis of the results, the POLIFACT statistical program was used - analysis of variance for completely randomized multifactorial experiments.

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